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BEHAVIORAL EFFECTS OF CHRONIC EXPOSURE TO IMPULSIVE NOISE IN PR--ETC(U)
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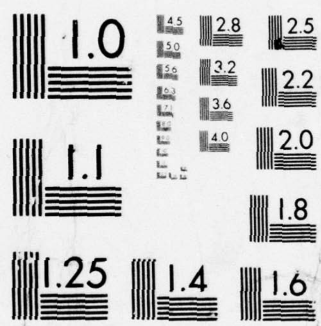

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BEHAVIORAL EFFECTS OF CHRONIC EXPOSURE TO IMPULSIVE NOISE IN PRIMATES

ALBANY MEDICAL COLLEGE
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JOINT DOT/USAF STUDY

DEPARTMENT OF TRANSPORTATION ★ UNITED STATES OF AMERICA ★

Aerospace Medical Research Laboratory

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FINAL REPORT

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TECHNICAL REVIEW AND APPROVAL

AMRL-TR-75-42

The experiments reported herein were conducted according to the "Guide for the Care and Use of Laboratory Animals," Institute of Laboratory Animal Resources, National Research Council.

This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

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16. Abstract

Two young female chimpanzees were exposed to 35 impulsive acoustic stimuli each night for 180 consecutive nights. Daytime performance on a temporal discrimination psychomotor task deteriorated following initiation of the acoustic exposures. Adaptation to baseline performance was observed for one subject and suggested for the other. Both exhibited preexposure performance after the impulses ceased. Cage movements were measured for both subjects in response to every impulse noise presentation over the 180 days. The study demonstrated performance decrements which showed adaptation over time as well as general behavior changes and sleep interference which did not show adaptation over 180 days. All behavioral changes which occurred during the exposure disappeared after the noise exposures were terminated.

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PREFACE

This study was accomplished as a joint effort of the 6570th Aerospace Medical Research Laboratory, Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio and the Albany Medical College, Holloman Laboratory, New Mexico. The research was conducted under AMRL Project 7231, "Biomechanics of Air Force Operations: Effects of Mechanical Forces on Air Force Personnel," Task 723103, "Effects of Operational Noise on Air Force Personnel," and Work Unit 17, "Whole-Body Effects of Air Force Noise on People."

This work was supported in part under Inter-Agency Agreement DOT-FA70WA1-181, Human Response to Impulsive Acoustic Stimuli, between the Department of Transportation, Federal Aviation Administration and the United States Air Force, Aerospace Medical Division. The Department of Transportation technical monitor for this effort was Mr. Thomas Higgins.

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Introduction

Research on the disruptive effects of sudden loud noises on behavioral capabilities of human subjects has revealed a wide range of results. Most sudden and unexpected noises, which create startle in subjects, produce transitory impairment of performance which typically disappears immediately after cessation of the noise (2,3,4,5,6,7,9,12). On the other hand, some studies detect little to no significant behavioral impairment while still others find actual improvement in the performance of certain tasks while exposed to the same type stimuli (8,13,14). When the nature of the impulse, i.e., suddenness, loudness, etc., is not sufficient to produce startle effects, behavioral responses such as performance are ordinarily unaffected.

Virtually all research efforts to date have observed acute behavioral changes during and immediately following the presentation of the impulsive noise. These immediate effects are not too difficult to evaluate for particular tasks. However, the data are not sufficient to permit the estimation of behavioral effects during and following long term exposures to such noises. Acute behavioral changes provide no information on either adaptation or persistency effects of long term exposures. Although experience reveals that humans adapt remarkably well to various noises, even during the sleeping hours, little information is available for acoustic impulses. Interference effects on performance which are observed to disappear shortly after the impulse during brief studies may carry over into other activities if the impulses are experienced over many weeks and possibly months. The general question concerns the observation of behavioral responses during and following exposure to impulsive noises over many weeks and months.

It is immediately clear that the use of human volunteers for studies lasting many weeks is not feasible. Human subjects are just not available for the required daily participation over the extended time periods nor can precise experimental controls be exercised over these people outside the test situation. Actually, subjects should remain in the test situation throughout the entire experiment to insure the most precise controls. Although not previously used, conditioned primates are considered to be highly suited to the experimental demands of long duration studies and offer a unique research opportunity. In addition to the main program, this report briefly describes an earlier pilot study which demonstrates the feasibility of an experimental program in which primates instead of humans may be employed to evaluate long duration noise, adaptation and persistency effects.

It was determined that primates conditioned to perform a psychomotor task during the waking hours would be exposed to several impulsive acoustic stimuli during the sleeping hours. In addition to the direct effects of the stimuli on sleep behavior, possible persistency or residual effects of the nocturnal stimuli on daytime performance could be observed. Daily exposures over a period of six months were believed to be adequate to reveal adaptation and persistency effects due to the acoustic impulses.

In the pilot study, two young male chimpanzees were trained to perform a complex psychomotor task involving temporal discrimination, i.e., subjects learned to perform a task only during a brief ten second "window" or interval of time which occurred after a thirty second delay following the "start" signal. The subjects were exposed to 24 impulsive noises each night for 30 consecutive nights. During the exposure period, the daytime performance on the temporal discrimination task was significantly poorer than the preexposure baseline performance. The greatest performance decrements occurred on the days shortly after the impulse noise exposures were initiated. Although the amount of degradation decreased over time during the exposure period, suggesting that adaptation to the noise may have been taking place, the performance decrement had not fully disappeared after 30 days of nocturnal exposures.

Gross body movements of the subjects in response to the impulse noise presentations were indicated by lateral movements of the cages. Accelerometers mounted on the cage housings were activated for a period of time from prior to until after the impulse presentations to allow direct correlation of movements with noises. Cage movements from both subjects resulted from every impulsive noise presentation during the entire exposure period. No changes in the nature of these gross body responses were observed during the course of the study.

The general health and cooperation of the subjects were not adversely influenced by the confinement. Behavior patterns and interaction with attendants were observed to be typical and unchanged during the training, exposure and post-exposure phases of the study. Overall, the pilot study demonstrated that the use of primates to assess long term exposure effects of impulsive exposures is both feasible and practical.

Purpose

The purpose of the present study was to determine the effects on daytime psychomotor performance of nocturnal exposures of chimpanzees to impulsive noises experienced daily over a six-month period. General health and hearing function were measured and behavior patterns observed during the course of the program.

Subjects

Two female pre-adolescent chimpanzees (designated subjects I and II in this study) were selected from the animal colonies at the International Center for Environmental Safety, Albany Medical College, Holloman AFB, New Mexico. Their weights at the outset of the experiment were 25.9 Kg and 26.8 Kg respectively. Their physical conditions were normal as determined by examinations consisting of general clinical assessment, EKG, roentgenograms (AP) and EENT, as well as fecal, urinal and hemotological analyses.

Apparatus

Test Space. Subjects were housed in performatory cages 79 centimeters (31 inches) wide, 152 centimeters (60 inches) deep and 152 centimeters (60 inches) high. One wall of each cage was fabricated from clear plastic of 1 centimeter (3/8 inch) thickness. All other walls were constructed of expanded metal. The cages were positioned and anchored in a large control chamber 234 centimeters (92 inches) wide, 452 centimeters (178 inches) deep and 257 centimeters (101 inches) high with insulated walls 15 centimeters (6 inches) in thickness. Figure 1 is a photograph of the cages inside the control chamber (door open) showing relative placement. The ambient temperature was maintained at 22 degrees C (72 degrees F) and the relative humidity was maintained at 60% inside the test chamber.

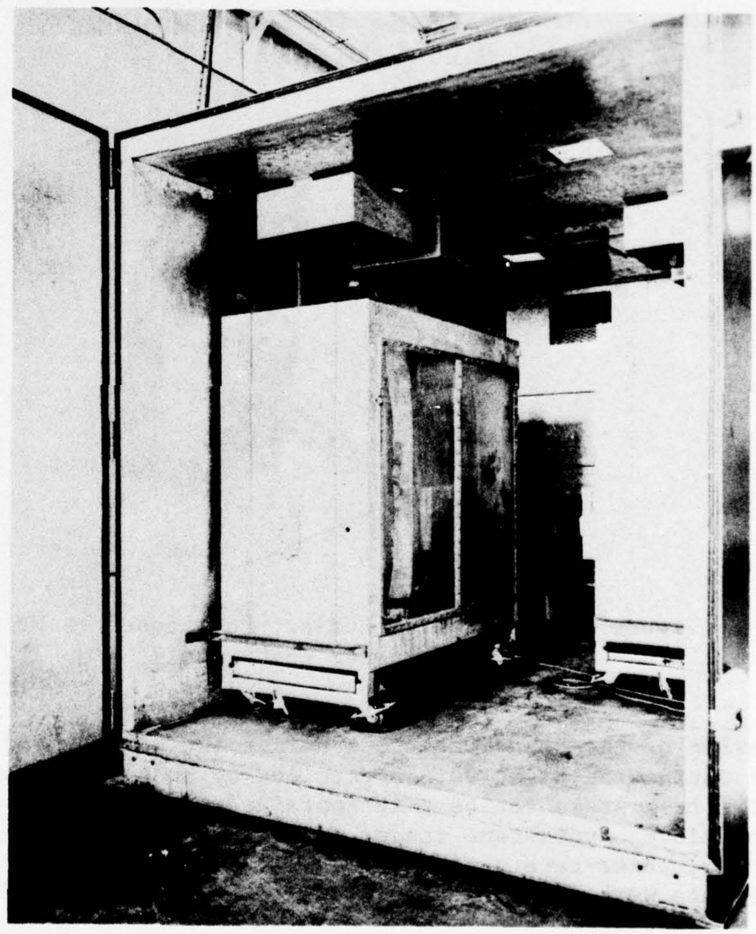

Figure 1. Relative Placement of the Performatory Cages Inside the Control Room, Location of the Stimulus Loudspeakers, Accelerometer to Detect Cage Movements, and Manner in which Cages were Secured to Control Room are Visible.

Behavior Assessment

A psychomotor performance task was attached to each cage. Located inside was a performance panel which contained a response lever located 81 centimeters (32 inches) above the cage floor and requiring 250 grams of force in a downward direction to activate an electric switch. (See the sketch in Figure 2). All subject responses were recorded; however, on correct responses the electric switch activated an automatic food dispenser located on an outside wall which released a 300 milligram food pellet into a food well accessible to the subject. A 2.54 centimeter (1 inch) yellow light was located 15 centimeters (6 inches) above the response lever and served as the activating stimulus for the behavioral task. Drinking water was always available to the subjects.

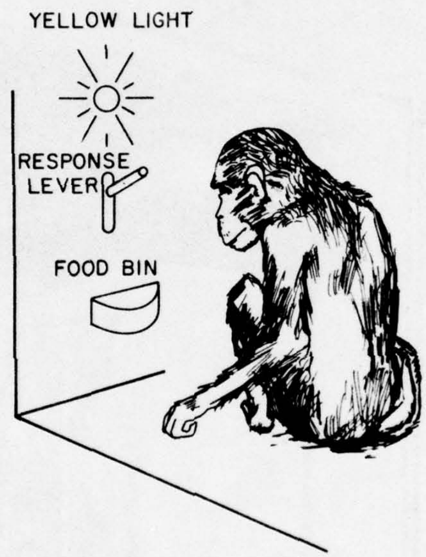

Figure 2. Drawing of Subject Positioned in Front of Performance Task Panel.

Presentation of the behavioral task during the workday and of the noise impulses during the night were controlled by an electronic programming unit. The task presentation unit contained a solid-state programmer, precision clock, punch-tape reader, electro-mechanical counters, print-out counter, paper-tape punch and associated logic packages. Behavioral response data were tabulated and processed with a Hewlett-Packard general purpose computer.

Body movements of the subjects, which were interpreted as startle reactions to the impulsive noise, were measured during the night by monitoring cage movement. A Statham ($\pm$10 g sensitivity) accelerometer was mounted at an upper corner of each cage (see Figure 1 for location) and calibrated to

detect lateral movements of the cages. The accelerometer outputs were recorded in analog form on a Sanborn 350 oscillograph. Also recorded by the oscillograph, on a channel parallel to the cage movement responses, were the impulsive noise presentations. This arrangement allowed cage movements and noise presentations to be readily correlated. Although the cages were solidly anchored to the walls and floors of the test chamber, movements of the chimpanzees during sleep were reliably recorded. of the test chamber. The waveform of the impulse displayed on the face of an oscilloscope was similar in configuration to that of a square wave with rapid rise and decay times and a duration of 300 msec. The sound pressure levels of the noise burst were measured with the Bruel and Kjaer system described earlier. The overall sound pressure level at the loudspeakers outside the cages reached 120 dB, however, the levels throughout the test spaces occupied by the subjects were 108 dB. the octave band levels are described in Table 2. The equivalent A-weighted level of the spectrum is 108 dB.

TABLE 2

OCTAVE BAND SOUND PRESSURE LEVELS*
OF NOISE BURST AT LOCATION OF SUBJECTS

	Octave Band Center Frequency (Hz)							
OASPL	63	125	250	500	1000	2000	4000	8000
108	90	92	92	100	104	104	92	90

*Sound Pressure Level in dB re $20\mu N/m^2$
(20µ Pascals)

Acoustic Environs

Background Noise. Ambient noise levels were measured inside the test chamber with cages in position, and with temperature and humidity control systems in operation, but without the subjects in their cages. The standard psychoacoustic procedure of taking ambient noise measurements with subjects absent from the test space was empicyed because sound pressure levels varied intermittently with the activities of the subjects inside the metal cages. The overall sound pressure level was 80 dB as measured with a Bruel and Kjaer Sound Level Meter (Model 2203) and Octave Band Filter Set (Model 1613) and a 2.54 centimeter (1 inch microphone (Model 4131). The actual octave band levels are shown in Table 1. The equivalent A-weighted level is 65 dB.

TABLE 1

OCTAVE BAND SOUND PRESSURE LEVELS *OF
BACKGROUND NOISE IN TEST CHAMBER
WHEN NOT OCCUPIED BY SUBJECTS

	Octave Band Center Frequency (Hz)							
OASPL	63	125	250	500	1000	2000	4000	8000
80	74	68	63	62	60	54	50	50

*Sound Pressure Level in dB re $20\mu\ N/m^2$
(20μ Pascals)

The level of the ambient noise was sufficiently low as to pose no problem to the hearing of the subjects for continuous 24 hour exposures.* The noise standards of the Williams-Steiger Occupational Safety and Health Act of 1970 Title 29, Part 1910 (11) set forth 90 dBA** as the maximum permissible open-ear 8-hour daily exposure. Extrapolating from 8 hours out to 24 hours exposure reduced the allowable level to around 82 dBA. The ambient levels shown in Table 1 are equivalent to about 75 dBA which is well below a level at which temporary threshold shift might ordinarily be observed.

Impulsive Stimulus. The impulsive acoustic stimulus was generated by a Grason-Stadler white noise generator and amplified by a McIntosh amplifier (amplifier replaced by a Bogen Challenger amplifier during the program). The noise was shaped to an impulsive burst being controlled by a precision timing clock and presented to the subjects over four large loudspeakers mounted over the cages (loudspeakers are shown in Figure 1) on the ceiling

Procedure

Subjects were trained on a behavioral task based on a schedule of reinforcement generally termed "Differential Reinforcement, Low Rate (DRL), With Limited Hold." A visual stimulus (yellow light), used to advise the subject of the task status, was alternately presented "on" for fifteen minutes and "off" for fifteen minutes throughout the seven hour work portion of the test day. During the light "off" time the performance unit would not operate. During the light "on" time, in order to obtain a reward of a 300 milligram pellet of food, the subject was required to delay its response for a minimum of 30 seconds and a maximum of 40 seconds

* Assumption of similar susceptibility to noise exposure as the human ear.
**A-weighting is the standard electrical weighting network of sound level meters which corresponds to the loudness level of the human ear at the 40 phon equal loudness contour (cuts off low and high frequency energy).

after initial onset of the yellow light or subsequent completion of a response. Time was measured from the initial onset of the light stimulus to the first response. Then, each response would reset the timing cycle and serve as the time reference for the next delayed response. Only that response which fell within the 10-second interval between the thirtieth and fortieth seconds, measured from the last preceding response, was rewarded. A maximum of 30 correct responses could be made during each 15 minute session, provided the subject always responded at the nominal delay time of 30 seconds.

Subjects lived in the performance cages for a period of seven months during which acclimation and conditioning were accomplished. Performance during the last 20 days preceding initiation of the impulse exposures was measured and treated as the baseline or reference performance levels. Task performance had reached asymptotic levels prior to collection of the baseline data. At that time, regular daily work schedules were implemented. Lights in the chamber were extinguished at 9:00 P.M. and illuminated again at 6:30 A.M. At 8:00 A.M. the sequence of performance task programming was begun and continued until 3:00 P.M., comprising fourteen performance and fourteen rest sessions. Following completion of the series of behavioral tasks at 3:00 P.M., the test chamber was opened, the cages cleaned and supplemental food given to the subjects. The chamber was resealed at 4:00 P.M. Once each week (Friday at 3:00 P.M.) the subjects were removed from the performance cages which were then steam cleaned. This procedure, which included the supplemental feeding, usually required about 90 minutes after which the subjects were reinserted into the cages and the chamber was resealed.

Following the twenty day period during which baseline data were collected, the nighttime impulsive noise exposures were begun. Subjects experienced 35 impulsive noises each night for 180 consecutive nights. The impulsive noises were presented in semi-random order so that their occurrence could not be anticipated by the subjects. The only exception was the first impulse each night which was always presented at 9:30 P.M. The time intervals separating the impulses varied between 5 and 25 minutes with a mean of approximately fifteen minutes. No impulsive stimuli were presented after 6:00 A.M.

Criterion Measures

Performance Efficiency. Performance efficiency was calculated as the ratio of the actual number of reinforcements in a session to the possible number of reinforcements. For example, when a subject obtained 25 reinforced responses in a session during which there was opportunity for 29 correct responses, the 25/29 ratio provided the criterion score of 84% performance efficiency. The performance efficiency scores for the fourteen individual sessions from 0800 to 1500 hours were averaged to provide a mean daily performance score.

Performance Errors. The average number of errors per session, or performance errors, were defined as subject responses, i.e., depressing the lever, which occurred outside the time frames in which reinforcement was available (no reinforcement for error responses).

Correct Response Time. The average amount of time delay between the alerting signals and the correct responses by the subjects was described as the average correct response time.

Cage Movements. Cage movements during the night were monitored and compared with the occurrence of the impulse noises. The reduction in frequency of occurrence or cessation of cage movements with continued exposure would be interpreted as adaptation to the impulse noise.

Blood Pressure. Weekly measures of blood pressure of one of the subjects were taken with a pressure cuff system modified to accommodate the chimpanzee arms (i.e., Baumanometer).

Auditory Measures. Auditory function of both subjects was tested prior to the experimental exposures, after 120 days of exposure and following cessation of the exposures using the technique of evoked cortical response audiometry (1).

The criterion measures obtained during the experimental (exposure) and post-experimental periods were compared with the pre-exposure or baseline data in order to identify effects, if any, of the nocturnal impulses.

Results and Discussion

General Health. A total confinement of over one year in the experimental chamber was required to complete the training, acclimation, baseline, experimental and post experimental phases of the program. At the completion of the program the state of health of the subjects was found to be good as determined by physical examinations and laboratory analyses which included general clinical assessment, EKG, roentgenograms, EENT as well as fecal, urinary and hematological analyses. Body weight of the subjects was measured each week and results are summarized in Table 3. No body weight changes could be related to the noise exposures. The small increase in body weight observed for both subjects over the eight month period can be attributed to growth and normal development. Although no quantitative measures were taken, observations by the experimenters suggested that the gross musculature of the animals appeared weak on the day of their release from the study presumably because of the prolonged confinement and lack of opportunity for exercise. However, by the third day of their return to the large home cages, where opportunity for free movement and exercise was available, the observed symptoms of weak muscles had fully disappeared and the physical activities of the two experimental animals was not differentiated from that of the other chimpanzees.

TABLE 2

WEIGHT OF SUBJECTS
DURING COURSE OF PROGRAM

DATE	SUBJECT I	SUBJECT II	DATE	SUBJECT I	SUBJECT II
Baseline					
Nov 3	24.9*	26.8	Mar 2	26.3	28.6
9	26.3	28.1	9	27.7	29.5
17	25.9	28.6	16	27.2	28.1
Experiment			24	27.2	28.1
Nov 24	25.4	26.8	30	27.2	27.7
Dec 1	25.4	26.3	Apr 6	27.7	28.6
8	26.8	27.7	12	27.7	29.0
15	26.8	28.1	20	26.8	28.6
21	26.8	27.2	27	26.8	28.6
29	26.8	28.6	May 4	26.8	29.0
Jan 5	26.8	28.1	11	26.8	29.0
12	26.3	26.3	18	25.4	28.1
19	26.3	28.6	Post-Exposure		
26	26.3	28.1	May25	26.8	29.0
Feb 2	26.8	27.7	Jun 1	27.2	28.1
9	26.3	28.6	8	27.2	28.1
16	26.3	29.0	15	26.8	27.7
23	26.5	28.1			

*Weight in Kilograms (1 Kilogram = 2.2 pounds; 1 pound = .45359 Kilograms)

Experienced animal psychologists and handlers, through training, experience, and the immediate overt behavior of animals, learn to interpret the "attitudes" of animals toward attendants and experimenters in studies such as this one. It appears that the "attitudes" and cooperation of the experimental subjects clearly changed during the course of the long program. During the training, acclimation and baseline phases both animals were observed to be responsive to and playful with the attendants during the daily feeding and cage cleaning times. Vocalization, "presentations" (extending a hand toward the attendants), and water squirting were routinely observed. However, as the experiment progressed and impulse exposures continued the reactions of the subjects gradually changed. Nominal behavior such as vocalization, "presentations," and the like, became less frequent and finally were not observed at all. In addition, threatening postures and simulated attacks toward the attendants appeared and increased in number. Clearly, the subjects became less cooperative and interacted less with personnel during the course of the study. On the other hand, during the post-experimental period and after the subjects were removed from the experimental situation, this behavior was reversed and that type observed during the pre-exposure phases of the program reappeared. It is noted that full cooperation and interaction with attendant personnel was observed for the total pilot study. The uncooperative and negative behavior described herein, did not appear in the 30 day program.

The behavior exhibited by the subjects towards the attending personnel clearly deteriorated as the impulse exposures were begun and continued. Although it is highly likely that the nocturnal impulse noises were the primary contributor to the observed changes in behavior, the influence of the long duration confinement cannot be separated from that of the acoustic exposures. Hind sight indicates that a third subject, used as a control (treated identically to the other subjects, without acoustic exposures) would have provided the basis for a better interpretation of the behavior changes.

Average Performance Efficiency. Performance efficiency is defined as the ratio of correct responses to possible correct responses in one fifteen minute work session. Average daily performance efficiency is the mean value of the fourteen sessions accomplished during one day. For purposes of data treatment and analyses raw data scores were used. However, to display overall effects data were averaged over 20 day periods to provide a single average performance efficiency score for each period. Average performance efficiency for both subjects is plotted in Figure 3 for the total program. The 20 day averages are designated as A, B, C. . . I with the baseline (BL) and post-experiment (PX) data points also representing 20 day averages. The stippled area represents ± 1.96 standard error of the mean or the region around the mean within which 95% of the responses would be expected to fall. Data points falling outside this range, which was calculated using the baseline performance data, are considered to be significantly different from the mean.

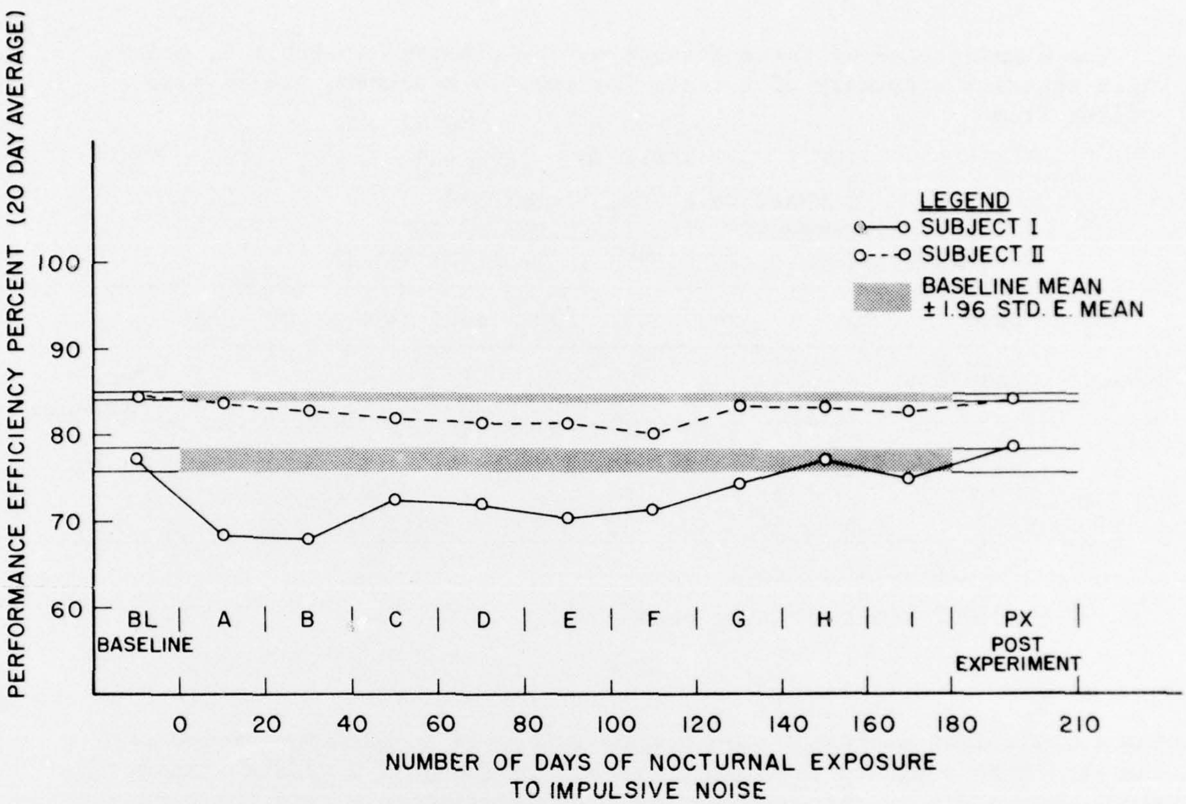

Figure 3. Average Performance Efficiency of Both Subjects During Program

The performance levels of the subjects were reasonably good, reaching asymptote during training and remaining at about 78% for Subject I and 85% for Subject II until acoustic impulse exposures began. It is evident from Figure 3 that Subject I exhibited an immediate significant drop in performance efficiency following the start of the nocturnal acoustic exposures. Although the initial shift was rather dramatic, this subject gradually improved her performance until after the 140th day when it had returned to the baseline level. Performance during the post-experiment period was slightly better than baseline. The performance of Subject II was reasonably stable. A slow deterioration of efficiency was observed until the 120th day of exposure after which a slow trend towards recovery is observed. The maximum performance degradation of Subject II did not reach that of Subject I; however, Subject II did not regain the baseline level of performance until during the post-experimental period.

The significance of these changes may be observed in Table 4, below, which contains a summary of t tests for related measures. It is also evident from

TABLE 4

SUMMARY OF t TESTS COMPARING
PERFORMANCE EFFICIENCY DURING AND
AFTER IMPULSE EXPOSURES TO BASELINE VALUES

	Days	20	40	60	80	100	120	140	160	180	
Subject	Baseline	A	B	C	D	E	F	G	H	I	Post-Exposure
I	---	* 5.11	* 6.66	* 4.12	* 4.33	* 5.72	* 5.36	1.99	0.01	1.75	1.82
II	---	1.52	* 3.14	* 4.40	* 6.31	* 3.70	* 4.33	** 2.42	* 2.86	** 2.35	0.49

*0.01% Level of Confidence

**0.05% Level of Confidence

the t tests that subject I performance recovered to baseline by 140 days and that both subjects returned to normal in the post-exposure period. These data indicate that average performance efficiency deteriorated as a consequence of the nocturnal noises. Adaptation was observed in one subject after 140 days, whereas the other subject showed a similar trend but did not adapt during the exposure period. Both subjects displayed the pre-exposure performance efficiency after the impulse noises ceased.

Performance Errors. Subject responses (depressing the lever) which occurred outside the time frames in which reinforcement could be obtained were defined as performance errors. The same averaging procedures used with performance efficiency data were used to obtain average daily performance errors and 20 day average performance errors for analyses. The 20 day average values are plotted in Figure 4 for the total program.

Relationships between performance errors and efficiency are evident in Figure 4 and Table 5. The abrupt rise in errors and subsequent decrease to baseline level for Subject I is consistent with the performance efficiency data. The same relationship can be stated for Subject II except that the post-experimental sessions showed slightly more error than baseline while performance efficiency was satisfactory. The relationships between baseline mean errors and those of the exposure and post-exposure periods were evaluated by t tests. The summary table confirms the data in Figure 4.

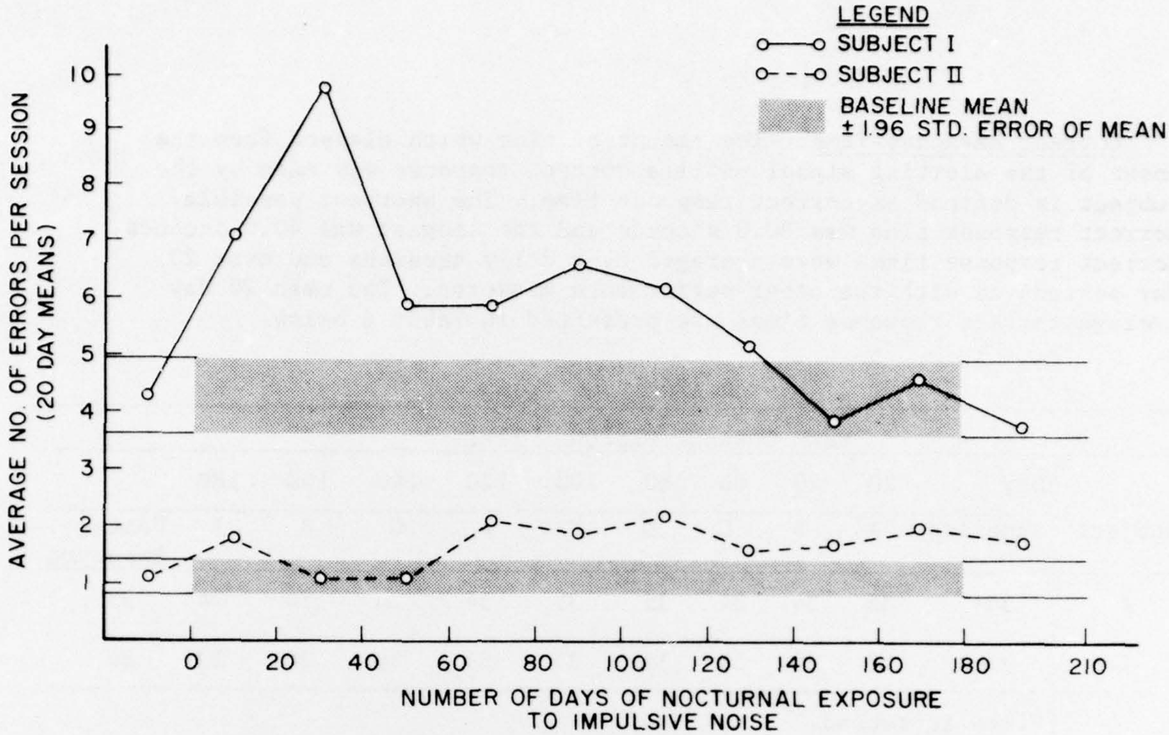

Figure 4. Average Performance Errors of Both Subjects During Program.

TABLE 5

SUMMARY OF t TEST COMPARING PERFORMANCE
ERRORS DURING AND AFTER IMPULSE EXPOSURES
TO BASELINE VALUES

	Days	20	40	60	80	100	120	140	160	180	
Subject	Baseline	A	B	C	D	E	F	G	H	I	Post-Exposure
I	---	4.54*	5.58*	3.51*	2.83*	4.77*	4.94*	2.02	1.09	0.48	1.27
II	---	3.56*	0.02	0.02	3.53	3.02*	3.92*	2.22**	2.25**	3.27*	2.53**

*0.01% Level of Confidence

**0.05% Level of Confidence

These data on performance errors support the conclusions reached on the basis of performance efficiency.

Correct Response Time. The amount of time which elapsed from the onset of the alerting signal until a correct response was made by the subject is defined as correct response time. The shortest possible correct response time was 30.0 seconds and the longest was 40.0 seconds. Correct response times were averaged over daily sessions and over 20 day periods as with the other performance measures. The mean 20 day average correct response times are presented in Table 6 below.

TABLE 6

MEAN CORRECT RESPONSE TIMES

	Day	20	40	60	80	100	120	140	160	180	
Subject	Baseline	A	B	C	D	E	F	G	H	I	Post-Exposure
I	35*	35	34	34	35	35	34	34	34	34	33
II	35	35	35	35	35	35	35	34	34	33	34

*Time in seconds

The data in Table 5 indicate that both subjects waited an average of 35 seconds before making a correct response. The optimum response time was the shortest time delay (30 seconds) which would allow the greatest number of response in a single work session of fifteen minutes. Initially both subjects responded midway in the reinforcement period, however, as the study progressed the average correct response times increased from 35 to 34 and 33 seconds. These increases of 1 and 2 seconds represent 10% and 20% improvements.

Although performance efficiency fell significantly and performance errors increased during the exposure, correct response times were not adversely affected and in fact revealed a trend toward the nominal time of 30 seconds. It appears that the improvements are related to practice effects which resulted in the observed decreases in response time by the subjects.

Cage Movement. The immediate effect of the acoustic impulses on sleep behavior was also investigated by observing cage movements during the night. Cage movements which occurred at precisely the same moment as the impulsive acoustic stimuli were interpreted as indications of sleep disruption experienced by the subjects. It is clear that each cage movement was not associated with the impulse noise, however, the analog records allowed reliable identification of those precipitated by the noises. In the pilot study in which two chimpanzees experienced 24

impulsive noises nightly for 30 consecutive nights, cage movement activity was observed for both subjects in response to each impulse noise presentation. Clearly, no adaptation had occurred in 30 days and longer duration exposure studies would be required to further investigate possible adaptation to the noise impulse during the sleeping hours.

The actual 20-day mean numbers of cage movements are shown for each subject in Table 7. The mean differences between the cage movements during impulse noise exposure and those of the baseline and the post-exposure values is striking. Statistical analyses of these data were not conducted because of the very large differences between the experimental and the control periods which are clearly significant. The cage movement behavior of Subject II is much more stable than that of Subject I as was her behavior in the case of all other factors evaluated. In spite of these individual differences between subjects, the observed effects on the criterion measures were essentially the same for both.

A comparison of the times at which the impulsive stimuli and the cage movements occurred in the present study revealed that every acoustic impulse during the 180 day period was accompanied by lateral movement of the cages. Information in the cage movement data was not sufficient to show detailed response variations over time, but only if a response did or did not take place, i.e., number of responses. Consequently, growth and/or habitation of this gross body movement in terms of magnitude of the response, if such adaptation occurred at all, could not be identified. Both subjects continued to respond to the impulsive noises over the 180 day period and no observable adaptation, in the form of disappearance of cage movement response, could be verified.

Blood Pressure. Measurements of systolic and diastolic blood pressures of Subject II were taken on a weekly basis. The general manner in which blood pressure measurements were taken is illustrated in Figure 5. Reliable measurement of these blood pressures is highly dependent upon the cooperativeness of the subject. Initially, Subject II was cooperative and satisfactory measures were obtained. However, as the study progressed the behavioral changes of reduced interaction with attendants and acute lack of cooperation exhibited by the subject were reflected in the blood pressure measures. This deterioration in cooperation and subsequently in reliability of blood pressure measurement results was culminated in the measurement attempts at about the fifteenth week of impulse exposures when the subject was totally uncooperative and no data could be taken. Following this experience, all attempts to record blood pressure failed.

The systolic and diastolic blood pressures taken during the course of the program are summarized in Table 8. The deterioration in subject cooperation is reflected in the increased variance in blood pressure

TABLE 7

TWENTY-DAY MEANS OF CAGE MOVEMENTS PER NIGHT

STUDY PHASE	DATES	NUMBER OF NIGHTS	SUBJECT I MEAN	SUBJECT II MEAN
Baseline	Nov 3 - Nov 22	20	4.45	0.35
A	Nov 23 - Dec 12	18	28.28	29.50
B	Dec 13 - Jan 1	18	86.89	83.39
C	Jan 2 - Jan 21	18	32.89	33.60
D	Jan 22 - Feb 10	20	38.95	25.25
E	Feb 11 - Mar 2	18	128.44	34.89
F	Mar 3 - Mar 22	19	61.21	29.74
G	Mar 23 - Apr 11	19	100.53	51.42
H	Apr 12 - May 1	20	29.65	25.00
I	May 2 - May 21	20	31.35	19.75
Post-Exposure	May 22 - Jun 20	24	3.71	0.04
Average of 20 Day Mean Number of Cage Movements			65.33	36.95

TABLE 8

BLOOD PRESSURE MEASUREMENTS
OF SUBJECT II

Data	Month	Day	Blood Pressure Systolic	Blood Pressure Diastolic
Baseline	November	3	160	125
		10	150	120
		17	160	135
Experimental	November	24	160	125
	December	1	180	150
		8	162	120
		15	140	115
		22	160	125
		29	160	125
	January	5	122	96
		12	142	102
		19	172	125
		31	145	100
	February	2	144	112
		9	160	119
		16	150	104
		23	158	100
	March	9	Subject refused to cooperate	
		16	150	100
	April	4	172	110
		6	192	66
		12	180	112

values. Initially, the values were relatively stable from week to week. However, from January on, weekly variations increased as did the differences between systolic and diastolic pressures. Although four to five attempts to measure blood pressure were made each week from March though April very little success was experienced. The values shown in the lower portion of the table are included only to illustrate the nature of the results and have no technical value because of their unreliability.

Unfortunately, the measures of systolic and diastolic blood pressure taken on Subject II were inconclusive. Although changes in blood pressure were measured, they were erratic and correlate more with changes in the behavior and cooperation of the subject than with the impulsive noise.

Evoked Response Audiometry. Auditory thresholds were measured using electroencephalic response audiometry prior to, during and following the impulse noise exposure period. This method utilizes electrical potentials of the animal cortex which change when the ear(s) is presented with auditory stimuli above detection threshold. Surface recording electrodes are positioned on the scalp of the subject from which the electrical signals are recorded and the auditory test signals are presented by headphones. Figure 6 shows a subject being prepared for audiometric testing. The arms of the subjects are restrained to prevent them from removing the headphones during the testing procedure. The determination of auditory threshold is sometimes a problem with this method, because as the test signal magnitude is decreased the electrical cortical response decreases and is difficult to detect at and near threshold. In spite of this difficulty, correlation between evoked response threshold levels and actual psychophysical threshold levels with human subjects is quite good.

The hearing threshold levels for both subjects were within the normal response range for both baseline and post-exposure audiometry. The tests taken about 120 days after the impulses were initiated revealed normal responses for Subject II; however, hearing changes were measured for Subject I. A temporary threshold shift (TTS), which is defined as temporary hearing loss, was measured at each test frequency. At the 6000 Hz test signal the evoked cortical response was depressed and not of sufficient magnitude to be measured. Although the change in hearing sensitivity for Subject I might be considered a consequence of the impulsive noise exposure, subject II exhibited normal hearing following the same exposure.

The NAS-NRC Committee on Hearing, Bioacoustics and Biomechanics has prepared proposed damage risk criteria for impulsive noise which have been widely implemented (10). According to these criteria, an impulse of 300 milliseconds duration can be safely experienced at peak pressure levels around and above 140 decibels as often as 100 times per day

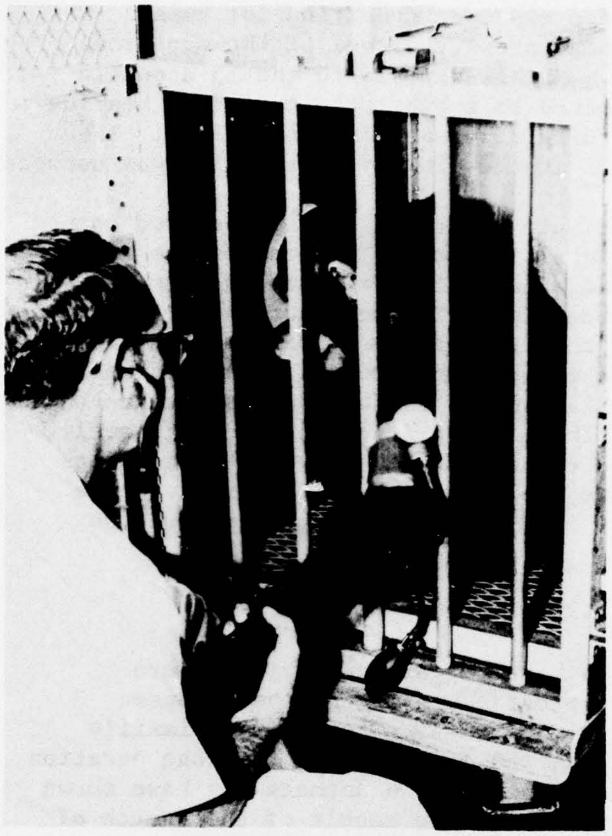

Figure 5. Blood Pressure Measurements Being Taken

Figure 6. Preparation of Subject for Evoked Response Audiometric Test

on a daily basis. This maximum safe exposure condition for humans greatly exceeds the 114 decibel sound pressure level of the nocturnal impulse noises used in this study. Humans exposed to the 35 acoustic impulses nightly would not be expected to exhibit the temporary hearing loss measured for Subject I, according to these limiting values. The hearing loss observed for Subject I at the 120 day test period was unexpected.

Evidence is not sufficient to attribute the cause of the measured change in evoked response solely to the impulsive noises in view of the above, of the subject differences observed, and of the presence of normal hearing in subject I on the tenth day following termination of the impulsive noise exposure. It is clear that the discovery of the significant change in hearing should have been investigated more closely at the time by several repeat audiograms at brief intervals in order to examine any further growth and/or recovery of the hearing function. Unfortunately, this was not accomplished and as a consequence the 120 day data points are of limited value. To attribute the changed hearing levels in the experimental subject solely to the impulsive noise exposure would be speculative.

Summary

Several well-defined changes in the behavior of the subjects were measured during the course of this program. Although the evidence strongly suggests that the acoustic type impulse noise was primarily responsible for the observed effects, the influence of the long duration confinement cannot be ignored. For example, the animals may have shown performance decrements without the noise, as a result of the length of time of the confinement. On the other hand, considerably more learning may have been observed on the performance task over the 180 days if the noise had not been experienced at all.

The general health of the subjects was good following over one year of confinement and six months of nocturnal impulse noise exposure. The overt behavior and cooperation of the animals changed from a positive "posture" to a negative "posture" which began during and persisted until the termination of impulse noise exposures, when it was again reversed to positive. The extent to which this negative "posture" influenced performance cannot be determined, however, it was clearly responsible for the failure of the blood pressure measurement phase of the program.

Average performance efficiency deteriorated following initiation of exposures to the nocturnal impulse noises. Adaptation to baseline performance levels was observed for one subject and was suggested for the other. Both subjects regained the pre-exposure performance efficiency after the impulses ceased. Performance errors correlated well with degradation of performance efficiency. Correct response

time improved over time and appeared to be due to the progressive change effect of practice with the task.

Cage movements were measured for both subjects in response to every impulse noise presentation over the 180 day exposure period. No observable adaptation, in the form of disappearance of cage movement response, could be verified. Blood pressure measurements were inconclusive. A temporary threshold shift in hearing for one subject measured at 120 days of acoustic exposure did not persist and was not present after the impulse exposures were completed. It is not clear that the measured reductions in hearing sensitivity were due to impulse noise exposure.

The implication of these findings for humans is that intense nighttime impulsive exposures over long time periods might be expected to interfere with sleep, even though awakening did not occur. Total adaptation of the sleep response would not be expected to occur for stimuli of sufficient magnitude to produce this startle response although tolerance might increase somewhat for many persons. Performance would be expected to be much more resistant to interference in humans because of the many personal, environmental and motivational factors which influence human performance. No basis is provided to expect any change in blood pressure. Impulse noise hearing damage risk for humans would suggest no impulse noise induced hearing loss for humans even though the hearing of one of the primate subjects exhibited an unexplained temporary change.

The study demonstrated performance decrements which showed adaptation over time as well as general behavior changes and sleep interference which did not show adaptation over the 180 day exposure period. All performance and behavioral changes which occurred during exposure and were attributed to the impulsive noises, disappeared after the noise exposure was terminated.

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